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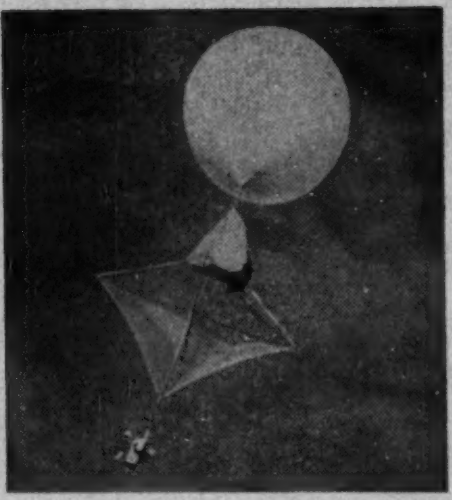

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SEISMOLOGY AT ESKDALEMUIR OBSERVATORY

By L. JACOBS

The primary purpose of establishing a new observatory at Eskdalemuir,[1,2] Dumfriesshire, in 1908, was so that geomagnetic records could be obtained in a place free from local disturbances, such as were affecting Kew Observatory when electric tramways were extended to the area at the beginning of this century.[3] Shortly afterwards, in July 1910, seismological recording with the then new Galitzin instruments was started at Eskdalemuir, the installation being supervised by Prince Galitzin himself. When geomagnetic recording was finally abandoned at Kew, the Galitzin seismographs were transferred there, in 1925, from Eskdalemuir and, after a period of recording in the basement at Kew, when the records were much disturbed by strong winds rocking the building, were placed, in 1937, in a new vault[4] in which recording has continued up to the present time.

Interest has grown in recent years in the study of seismology, both from the general point of view of the scientific study of the structure of the earth's crust mantle and core in connexion with the understanding of earthquakes, and recently because seismic observations offer the best prospects for the detection of underground nuclear explosions which involves the difficult problem of distinguishing man-made explosions from earthquakes. Recent research has been directed to the refinement of instrumentation—fundamentally under the influence of electronics with the possibility of converting the data into a format suitable for computer work. There has also been the application of new processing techniques to well-known principles, e.g. by the United Kingdom Atomic Energy Authority (UKAEA) when analysing the results of the cross array of seismometers in the Eskdalemuir area.[5] It is worth noting that no new principle has emerged for recording earth movements; new seismometers, like all the older instruments, respond to the difference between the movement of the suspension point of a heavy pendulum and the much smaller movement of the pendulum itself. The usual conversion of the relative movement to a trace on a seismogram is by arranging for this relative movement to be that between a coil and a magnetic field, the current induced in the coil passing through a galvanometer, the light spot deflected by the galvanometer mirror giving rise to photographic recording on a seismogram on a rotating drum. The change in modern times, as just indicated, is to process the current by electronic means,

but the photographic recording is still an excellent and convenient method and, as will be seen later in this article, is that used for the new equipment recently installed in a new vault adjacent to Eskdalemuir Observatory.

The inadequacies of seismological technique began to be realized at the Geneva Conference of Experts in 1958,[6] when the first proposals were drawn up for a world-wide system for the detection of nuclear explosions. These shortcomings were further demonstrated when the analysis of underground tests in the United States, in the autumn of 1958, revealed a number of unsatisfactory features in the proposed detection system. Following this the Americans proposed, in 1959, a programme to improve the instrumentation of the seismograph stations of the world. It was realized that in order to hasten basic research in seismology, the instrumentation of the world network of seismograph stations must be improved and standardized in the same manner as the standardization of meteorological instrumentation.

In 1960 a committee of American seismologists was formed by the National Academy of Sciences and the National Research Council, to advise the Government Agencies on the choice of instruments and to determine the basis for selecting the stations to receive the equipment. This group of seismologists met in April 1960 to establish detailed specifications for the instruments. Their recommendations were:

> "....electromagnetic seismometers recording through galvanometers with conventional photographic recording drums will be most satisfactory. The same drum rates, direction of paper transport and ground motion combinations are recommended for all the stations. It is further recommended that high quality clocks and radio receivers be supplied with the seismograph so that all stations will have time service of uniformly high quality."

About this time the UKAEA was looking, in Scotland, where the seismic 'noise' level is much smaller than in southern England, for a suitable area to install the seismic array later described by Thirlaway.[5] The team making the test decided that the area around Eskdalemuir was very suitable and the central point of the array was fixed at about 4 km north-east of the Observatory. In tests for 'noise' level the best point near the Observatory itself was found to be on a rising piece of ground at Mass Knowe (Plates I, II and III) which is about ¼ mile distant from each of various sources of 'noise'—Davington Burn to the west, the minor road to the east, the activities at Nether Cassock Farm to the north and the general movement of staff in the Observatory grounds to the south, where there is also the 'noise' disturbance due to the roots of trees on the periphery moving in the shallow soil.

The International Seismological Summary Committee, at its Paris meeting in July 1961, pronounced the international requirement that all countries should work towards the ideal of a world network, having stations at intervals of about 1000 km. A circle of 1000 km centred in southern Scotland includes the whole of Ireland and the Low Countries and substantial areas of France, Germany and Scandinavia, so that one first class station at the centre of this circle is a sufficient United Kingdom contribution in relation to land areas. This point and the general need to have a first class station in a low 'noise' area were the main reasons why the Council of the Royal Society recommended, in January 1962, that Eskdalemuir Observatory be developed as the main recording base in the United Kingdom to provide for routine recording to international standards, for the development and operation of special instruments constructed

by other organizations and for the study of local earthquakes. (It is appropriate to recall that it was a Committee of the Royal Society which selected the site for the Observatory in the early years of the century.) It was agreed that the Meteorological Office should arrange for the return of seismological work, on an increased scale, to Eskdalemuir Observatory; this was particularly appropriate since Gassiot Fellowships[7] in seismology and geomagnetism had recently been approved for the Meteorological Office and also since the Seismic Research Group was being set up at the Royal Observatory, Edinburgh.[8]

In September 1961 the American offer was received of the gift of the standard American seismograph system for Eskdalemuir Observatory—one of about 125 stations to be so equipped over the world. This offer was accepted and it was planned that the equipment would occupy about a third of the space in the new vault at Eskdalemuir on the best available position at Mass Knowe described above, the remainder of the vault to be available for other seismic equipment. It so happened that there was a disused quarry in the required area; it was ascertained by local inquiry that there had never been any blasting which might have disturbed the underlying rock. After detailed planning, including consideration of features of other modern vaults, the vault was built in the latter half of 1963 without, of course, any blasting; it is of reinforced concrete, the interior being some 36 feet × 20 feet × 7½ feet high; the top is covered smoothly with some 3 feet of earth and the rough reedy grass is growing over. By making the excavation in the existing quarry in the side of a hill, the entrance to the vault (Plate III) has a normal doorway without steps; the underlying solid rock formation is Silurian shale (greywacke). A special feature of the vault is wire heating on the ceiling, controlled by a variable mains transformer, so that not only are there no abrupt changes of temperature, but the air remains stable so that disturbance to the instruments is as small as possible. There are also independently supported bridges for staff to walk on without affecting the piers on which instruments stand. (The vault is centred within a sheep-proof fenced compound, of about 230 × 220 feet, to eliminate disturbance due to sheep movements.)

The 'noise' level in the new vault was compared with that at Kew. In the first winter of measurements, for periods 0.125 to 0.25 seconds the 'noise' level at Eskdalemuir was about ½ millimicron (1 millimicron is 10^{-9} metres) compared with about 45 millimicrons at Kew; for periods 1 to 2 seconds the comparable figures are 20 and 75 millimicrons; as the period increases the figures approach until at periods 4 to 8 seconds the 'noise' level at Eskdalemuir is greater, 1.2 microns, as against Kew, 0.25 microns; presumably because Eskdalemuir is closer than Kew to the source of microseisms generated by waves in the Atlantic.

The American equipment was installed by two technicians from the U.S. Coast and Geodetic Survey, the agency responsible for equipping stations all over the world, in February/March 1964. There are short-period (about 1 second) and long-period (about 30–100 seconds) seismometers all recording via mirror galvanometers on photographic paper on rotating drums. Each seismometer records three components, vertical, north–south horizontal and east–west horizontal (Plates IV and V). Timing is controlled by a crystal oscillator in conjunction with a radio receiver (Plate VI). The installation was completed in time to record the severe Alaskan earthquake on 28 March 1964. Because of a large amount of microseism activity during the setting-up period the initial magnifications of the seismographs were set at 12,500 for the

short period and 750 for the long period,but these were later doubled. (At Kew the short-period vertical seismometer has a magnification of up to 3000 and the Galitzin instruments have a magnification of about 400–500.) Eskdalemuir thus became the 95th station of those planned for the world network. The seismograms from all these stations are sent at regular intervals to the U.S. Coast and Geodetic Survey Seismological Data and Analysis Center in Washington where they are copied on to microfilm and later returned to the station; microfilms or full-size copies of seismograms from all stations in the network are available, at a small charge, to scientists in any part of the world for independent research studies. An example of a seismogram is shown in Figure 1. The complete seismogram is 3 feet long and about 1 foot broad. The record starts on the top line, goes from left to right and resumes left to right on the second line and so on. The trace carries time marks at each minute (with special identifying marks at the hours and main synoptic hours). The portion displayed (about 2/3 original size) gives the trace for 12 minutes of each of 24 hours. The small movements over most of the trace are normal background microseisms but after the arrival of the shock wave from the Japanese earthquake at 0414 GMT (lower left) there are marked oscillations. At the end of the bottom line of the trace appears a large loop which is caused by a calibration check.

For future requirements of data logging of the recordings by electronic equipment in the vault, a 25-core shielded cable leads underground from the new vault all the way to the southern part of the Observatory grounds where a new surface laboratory for seismology is to be built; the cable path was chosen so that no interference is likely to be caused by the mains cable. The data can thus be logged on equipment in the laboratory and tapes from this equipment can be processed by electronic computers.

Thus a significant start has been made in re-establishing seismological work at Eskdalemuir. It was agreed at the Berkeley, California, meeting of the International Union of Geodesy and Geophysics in August 1963 that a new International Seismological Research Centre be established in Edinburgh and that the International Seismological Summary unit, located at Kew Observatory for many years, should be transferred to Edinburgh[9] when the present plan for dealing with the backlog of work is completed. Dr. P. L. Willmore, Senior Research Fellow in Seismology at the University of Edinburgh was appointed Director of these two new seismological groups. Dr. Willmore and his group are developing seismic equipment for recording on magnetic tape and expect to take advantage of the fact that the low 'noise' level in the vault at Eskdalemuir will enable such equipment to be operated at much higher sensitivity than at most other places in the United Kingdom. The spare space in the vault is, of course, available for use by other research workers in seismology.

In addition to the vault already completed at Eskdalemuir, it is planned, as stated above, to have a new surface laboratory; an extra married quarter and a hostel extension are also to be provided and at the same time there is to be an augmented water and electricity supply and a central oil-fired boiler house with underground ducts to lead the heating to all official and domestic buildings.

The annual report of the Meteorological Committee for the year ending 31 March 1928 has an interesting entry (p. 22):

> "In order to commemorate the connection of four eminent physicists with the Eskdalemuir Observatory, it was decided by the Meteorological

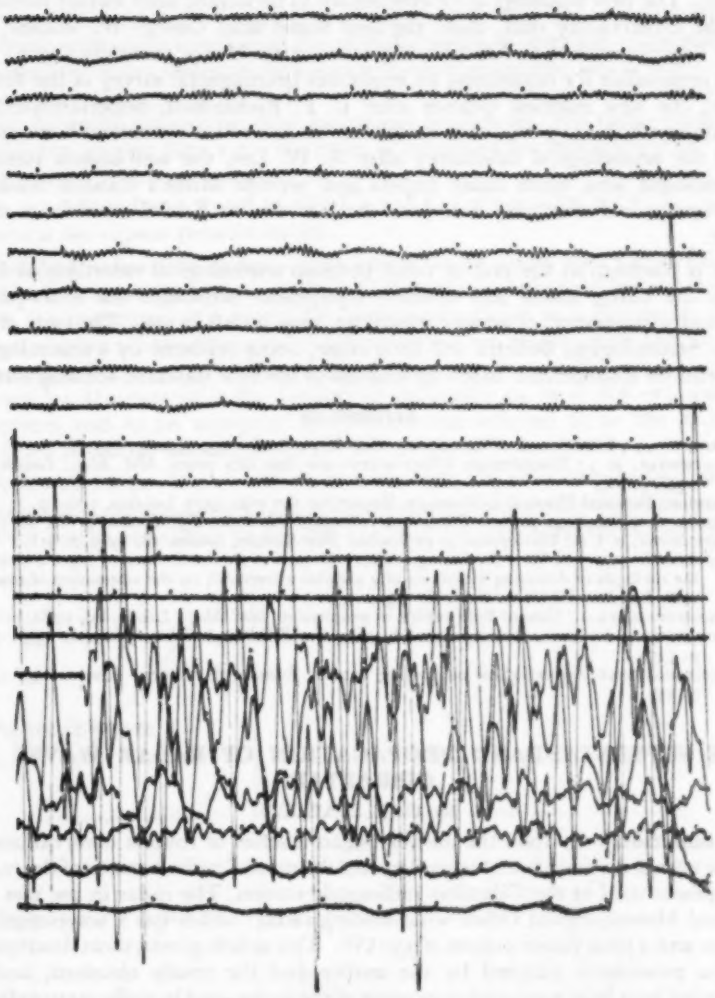

FIGURE 1—PORTION OF THE ESKDALEMUIR NORTH–SOUTH LONG-PERIOD SEISMOGRAM FOR 16 JUNE 1964 SHOWING THE ARRIVAL OF THE SHOCK WAVE, FROM THE JAPANESE EARTHQUAKE, AT 0414 GMT

Committee to give the four residential houses the following names: Superintendent's House, Rayleigh House, Assistants' House, Schuster House and the two houses recently erected for members of the staff Glazebrook House and Shaw House."

Rayleigh House and Schuster House, the present hostel, were two of the original buildings erected in 1908 when the Observatory was looked after by the National Physical Laboratory (the Meteorological Office took over in July

1910). The new buildings to be erected are to be named after former members of the Observatory staff, thus: the new hostel after George W. Walker, the first Superintendent at Eskdalemuir, who wrote *Modern seismology* (1913) and was responsible for organizing an important geomagnetic survey of the British Isles; the new married quarter after L. F. Richardson, Superintendent at Eskdalemuir in 1913–16, when he drafted his account of numerical forecasting; and the seismological laboratory after A. W. Lee, the well-known research seismologist who wrote many papers and rewrote Milne's classical book on *Earthquakes and other earth movements*—he was also at Eskdalemuir for a short time.

It is planned, at the end of 1964, to cease seismological recording at Kew with the older, much less sensitive equipment (although the short-period vertical seismometer, of greater sensitivity, may be left in use). The issue of the Kew Seismological Bulletin will then cease, being replaced by a seismological bulletin for Eskdalemuir based on analysis of the new standard seismograms.

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THE SUPERSTANDARD PROPAGATION OF RADAR WAVES AT GIBRALTAR

By C. J. STAPLEY

Introduction.—In 1960 the author began a series of routine observations of radar echoes received from targets beyond the normal radio horizon of the radar equipment used at the Gibraltar radiosonde station. The radar in use was the normal Meteorological Office wind-finding radar[1] which has a wavelength of 10 cm and a peak power output of 350 kW. This article gives a short description of the procedures adopted by the author and the results obtained, and is preceded by a brief explanation of some of the terms used in radio meteorology.

Refractive index.—The index of refraction n in dry air has the same value over almost the whole of the electromagnetic spectrum, being the same for radio and light waves. In the atmosphere $(n-1)$ is of the order of 300×10^{-6}. In order to avoid small numbers in calculation $(n-1) \times 10^{+6}$ is sometimes denoted by N where N is the number of millionths in $(n-1)$. Thus,

$$N = (n-1) \times 10^6 = Kp/T$$

where K is a constant which has a value of 79 for wavelengths greater than 2 cm, p is the air pressure in mb, T is the temperature in °K.

However, when water vapour is added to the dry air the value of N for the mixture becomes dependent on frequency. It can be shown that since water

molecules are polar in nature they have different responses to different frequencies. With the high frequencies of light waves they become electrically polarized; with the lower frequencies of radio waves, in addition to becoming polarized, the water molecules reorientate themselves rapidly and so follow the electric field changes. As a result the index of refraction of water vapour is greater for radio frequencies than for optical frequencies. For radio waves of wavelengths greater than 2 cm the index of refraction for atmospheric air can be calculated from the expression

$$N = (n-1) \times 10^6 = (79/T) \times (p - e/7 + 4800\, e/T)$$

where e is the vapour pressure in mb.

Modified refractive index.—Theoretical work[2] shows that for rays with small inclination to the horizontal a modified refractive index can be used which allows the curvature of a ray to be considered relative to a flat earth. The refractive index n is modified to $n + h/R$ where h is the height above the earth's surface and R the radius of the earth. In practice $(n + h/R - 1) \times 10^6$ is denoted by M where M is the number of millionths in $(n + h/R - 1)$ and is sometimes said to be measured in M-units and referred to as the M.R.I. (modified refractive index).

Types of duct.—The modified refractive index M may be calculated from associated radiosonde ascents. Typical examples of curves showing the lapse of M with height are shown in Figures 1(*a*) and (*b*) and such curves are more

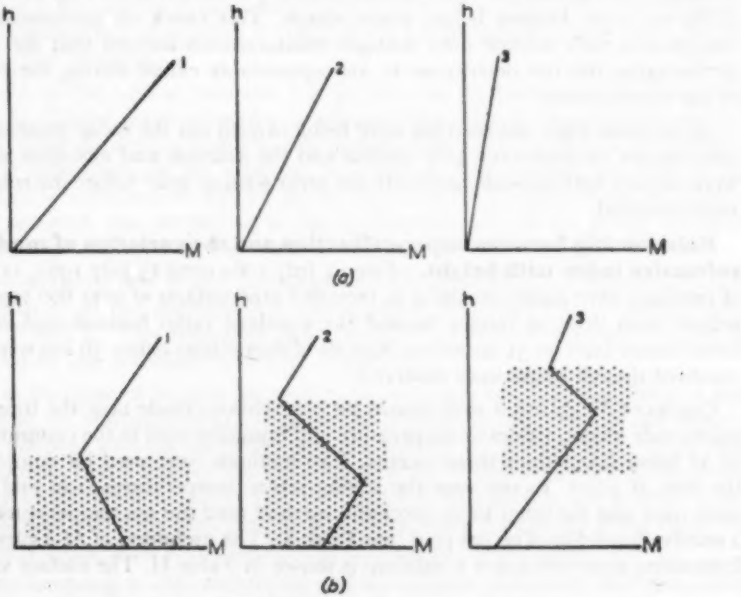

FIGURE 1—TYPES OF HEIGHT VARIATION OF THE MODIFIED REFRACTIVE INDEX (M-h CURVES)

(*a*) 1. Substandard type, 2. standard type, 3. transitional type.
(*b*) Superstandard types with ducts shown by stippling.
1. Simple Surface duct, 2. Ground-based S duct, 3. Elevated S duct.

fully discussed elsewhere.[2] For super-refraction it is necessary for M to increase with height less rapidly than usual. If M actually decreases with height a duct is formed in which rays from a transmitter within the duct may be trapped. The rays may be returned from a reflecting object also in the duct. If the duct exists over a great distance then echoes may be received from objects which are normally well out of radar range. Various types of duct are shown in Figure 1(*b*).

Radio horizon.—Under standard propagation conditions the radio horizon d is given in km by $d = 4.1\sqrt{H}$ where H is the height in metres of the aerial above sea level. The radar equipment at Gibraltar is situated close to the sea on the Mediterranean side of the colony and the aerial height is approximately 6 m above sea level thus giving a standard radio horizon of 10 km. If the height of a ship is taken to be 20 m then the maximum range at which such a target could be located by the radar under standard conditions is given by

$$d = 4.1\ (\sqrt{6} + \sqrt{20}) = 28 \text{ km}.$$

Procedure.—Searches for echoes from ships beyond the standard radio horizon were normally made immediately preceding or following a radiosonde wind or radar-wind ascent, the method of search being to rotate the radar aerials from 40 degrees to 180 degrees in azimuth, the elevation being kept at zero degrees. This method gave the radar beam a long sea track. In order to check that the radar equipment continued to operate at the same level of efficiency throughout the observations, several permanent echoes up to a range of 87 km were located before every search. This check on performance in conjunction with routine field strength measurements showed that the radar performance did not deteriorate to any appreciable extent during the period of the observations.

At all times while the searches were being carried out the radar presentation unit was set on automatic gain control and the azimuth and elevation signals were aligned both optically and with the error sensing unit[1] before the readings were recorded.

Relationship between super-refraction and the variation of modified refractive index with height.—From 4 July 1960 until 25 July 1961, 113 sets of readings were made, resulting in recorded observations of over 600 separate echoes from ships at ranges beyond the standard radio horizon and echoes from distant land on 34 occasions. Ranges of ship echoes below 36 km were not recorded though many were observed.

Curves of M against h were drawn for observations made near the time of a radiosonde ascent, values of temperature and humidity used in the computation of M being taken from these ascents. Two methods were used for computing the first M point. In one case the station screen temperatures (wet and dry) were used and the other more successful method used the sea temperature and a relative humidity of 90 per cent (see Table I). The usefulness of M-h curves in forecasting super-refractive conditions is shown in Table II. The surface values

TABLE I—SUCCESS IN FORECASTING SUPER-REFRACTIVE CONDITIONS

Temperature used to compute first M value	Number of forecasts of super-refractive conditions	
	Correct	Wrong
Sea	55	19
Station	42	32

of M used in the plotting of the curves considered in Table II were computed by using the sea temperature taken at the eastern side of Gibraltar and a relative humidity of 90 per cent. By doing this the initial decrease of M in the surface layers may be representative of the conditions along the path of the beam over the sea.

TABLE II—SUPER-REFRACTION AND TYPES OF M-h CURVES

Type of M-h curve plotted at time of observation (See Figures 1 and 2)	Number of occasions on which echoes due to super-refraction were recorded	Number of occasions on which echoes due to super-refraction were not recorded
Standard	5	2
Substandard	4	9
Superstandard		
(*a*) Simple Surface duct	33	8
(*b*) Ground-based S duct	3	1
(*c*) Elevated S duct	6	0
(*d*) Transitional	2	1

In the drawing-up of all the M-h curves the values of M were plotted at the surface height, 25 m and thereafter at intervals of 50 m up to a maximum height of 1000 m. This resulted in all types of M-h curves being recorded. The curves called transitional in this article are those in which the value of M at any point increases with height at a rate less than standard but does not become of negative slope (see Figure 1(*a*)).

Limitations of radiosonde measurements.—It can be seen from Table I that the forecasting of super-refractive conditions in coastal waters could be very misleading if no account is taken of the sea temperature when computing the surface M value.

Some of the wrong forecasts can perhaps be explained in the following manner. Where super-refractive conditions were known to exist and yet no echoes from ships were recorded, it is possible that no ships were in the vicinity to give reflections. In the instances in Table II where curves are seen to be standard or substandard and yet echoes from beyond the normal radio horizon were received, the limitations of the Radiosonde Mk 2B for giving detailed structure for this type of work must be considered.

The sampling rate of any particular element of pressure p, temperature T, or humidity U on the radiosonde is approximately 6 seconds per 18-second cycle of p, T and U. This represents approximately 120 ft out of a layer of 360 ft covered by one complete cycle of p, T and U.

If at the time of launch the switch on the sonde is at the beginning of the U signal, no temperature will be recorded during the first 200 ft of the ascent. This, coupled with the inherent lag of the type of hygrometer used, could very easily mean that a shallow duct existing near the surface would not be recorded by the sonde. Since a duct of only 10 ft in depth will allow a 10-cm wave to be propagated over long distances, such points as those mentioned above could be of much importance in the forecasting of super-refractive conditions.

The foregoing is only theoretical and the author cannot say that the sonde has failed to register a shallow duct which may have existed near the surface. In practice the sonde has proved reliable in recording the existence of a well-defined duct of the Simple Surface type.

Side lobes.—It was appreciated that during the observations the energy contained in the transmitter side lobes could also be extended in range when

super-refractive conditions were in evidence. A check was made to ascertain the exact position of these side lobes on the radar equipment. This check showed that the side lobes existed at 15 degrees and 30 degrees in elevation and at 21 degrees and 45 degrees in azimuth. For a reference signal input to the aerials of one micro-microwatt the energy in these side lobes was less than the energy in the main lobe by 25 decibels (dB), 43 dB, 25 dB and 25 dB. It can be seen from these measurements that a signal, under standard propagation conditions, would have to be of considerable power in order to be picked up on a side lobe and give a signal to noise ratio of 3 : 1, the figure at which the set is normally operated.

To test the location of ships in these side lobes the paraboloids were rotated until a ship was located in the main beam, the paraboloids were then moved to the side-lobe positions and a check made to see if the ship under observation showed up on the display unit. These tests were carried out under all propagation conditions.

Side-lobe reception.—The investigation into the effectiveness of ship location by means of side-lobe reception showed that under normal propagation conditions ships could be located by this means up to a maximum range of 5400 m. When super-refractive conditions were in evidence side-lobe reception became much more marked.

Under super-refractive conditions it was found that when a Ground-based S duct was present, ranges in excess of the standard radio horizon were recorded for side-lobe reception, the maximum range recorded being 57,000 m. The echo received at this range showed up in both azimuth side lobes but at the 15-degree position only in elevation. On the day that the side-lobe reception at 57,000 m occurred attempts to receive echoes on side lobes at ranges of 76,220 m and 78,850 m were unsuccessful.

On other occasions when a Ground-based S duct was present, echoes were observed in elevation and azimuth side lobes at ranges of 44,000, 49,500, 32,000 m; and, in elevation side lobe only, 21,000 m.

When an Elevated S duct was present the maximum range at which side-lobe reception took place was found to be 15,500 m. This was in the 21-degree azimuth position but not at all in elevation.

When a Simple Surface duct was present no instances of side-lobe reception were recorded during the period of observations.

Interference echoes.—At times during the normal radiosonde ascents, when super-refractive conditions were known to exist, difficulty in following the radar reflector suspended from the weather balloon has been encountered by the radar operators. This difficulty takes the form of interference from numerous echoes, apart from the one being followed. The interference swamps the indicator tubes and has taken place at elevations up to 30 degrees. The source of these echoes can sometimes be ascribed to the mountainous terrain over which the balloon is passing. On many occasions however the balloon track is over the sea and the unwanted echoes are most certainly from ships, and have the characteristic appearance of such echoes. The only explanation that can be offered is that the unwanted echoes are due to side-lobe reception. These occurrences are only noticed during operational soundings and in consequence further investigation is not always possible. On 19 August 1960 one such echo appeared on the coarse range tube at a range of 60,000 m during the 1700

GMT radar-wind ascent. When this echo was first noticed the paraboloids were at an elevation of 30 degrees. Shortly afterwards the balloon burst; the echo was then strobed and found to be at a range of 60,000 m and at zero degrees in elevation. This echo was without doubt the result of reflection from a ship and is assumed to be the result of side-lobe reception. The range at which it occurred however is greater than any recorded during the investigation mentioned earlier, and the ducts in evidence at 1100 GMT and 2330 GMT on this day were not the type, in the experience of the author, to give good side-lobe reception. Figures 2(*a*) and (*b*) show the *M-h* curves for the 1100 GMT and 2330 GMT ascents on 19 August 1960 together with the associated temperature and dew-point curves.

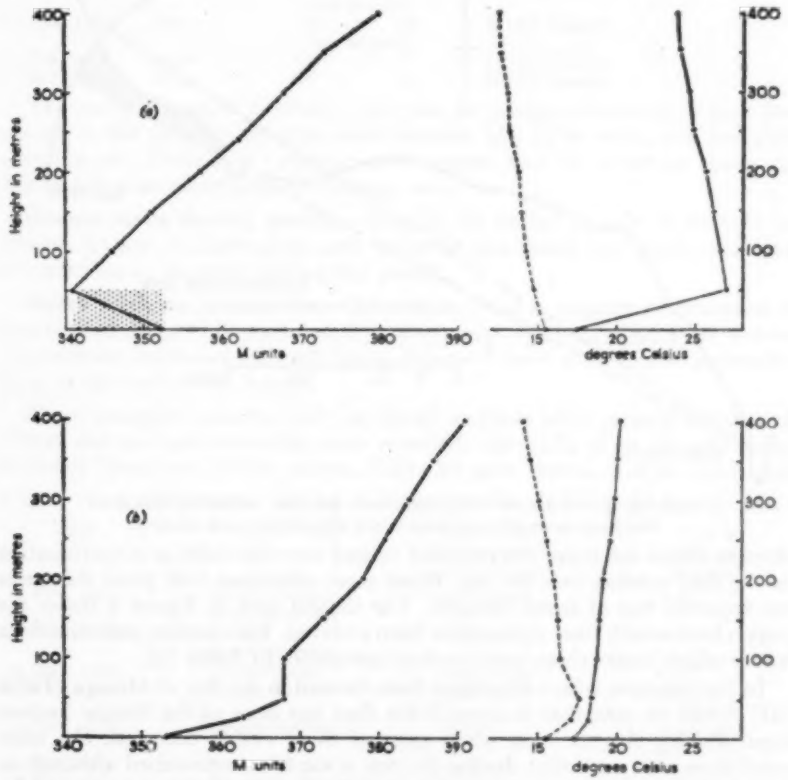

FIGURE 2—HEIGHT VARIATION OF THE MODIFIED REFRACTIVE INDEX, TEMPERATURE AND DEW-POINT ON 19 AUGUST 1960

(*a*) 1100 GMT (*b*) 2300 GMT

——— Modified refractive index, – – – dew-point, ——— temperature.
Stippling shows the ducts.

Land echoes.—Echoes having a slight to-and-fro movement have been received from land on 34 occasions, presumably from North Africa. From calculations and with reference to a 1:2,000,000 scale map the echoes appear to be reflections from the Middle Atlas mountains, the Saharan Atlas and the

coastal region around Oran. The distances involved range from 416 km to 464 km. These echoes are not seen on the radar unless super-refractive conditions are in evidence. For these echoes to have come from the areas mentioned they must necessarily be Multiple Time-base echoes.

Ducts over land and sea.—On a number of occasions the positions of the received echoes have been plotted and it has been seen that the radar beam has sometimes travelled over the sea and then over part of the Spanish coast to be reflected from ships in the Bay of Malaga (see Figure 3). Since the distances involved are greater than the standard radio horizon it would appear that the

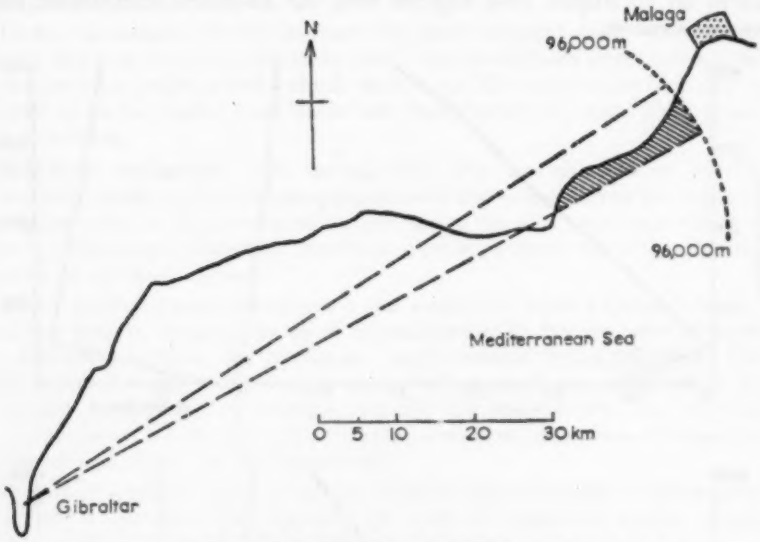

FIGURE 3—PLAN OF THE COASTAL REGION AROUND MALAGA
Hatching shows the area from which ship echoes were received.

duct in which the beam has travelled existed over the coast as a continuation of the duct existing over the sea. When these reflections took place there was no apparent loss of signal strength. The shaded area in Figure 3 shows the region from which these echoes have been received. The number and conditions under which these echoes were received are shown in Table III.

In the instances where ships have been located in the Bay of Malaga (Table III) it will be seen that in general the duct has been of the Simple Surface type. During August 1960 when most of these events occurred, the wind conditions were such that during the day a sea breeze prevailed although at night the wind was always from the land. Such a wind régime is normal for this area during the hot summer months. Ducts over the sea may be enhanced by the high surface-humidity over the very warm inshore waters, and during the day may be carried inland by the sea breeze thereby providing continuity of the duct from Gibraltar to the Bay of Malaga across the intervening promontory. At night the sea breeze dies away and the radiation cooling over the land would lead to a gradual destruction of the duct from the surface upwards. From the observations it would appear that at 2300 GMT the destruction process is still far from complete.

TABLE III—ECHOES FROM THE BAY OF MALAGA

Date	Time (GMT)	Wind at Malaga Direction	Speed *knots*	Type of duct	Number of echoes received
8 Aug. 1960	0001	NW (land breeze)	10	Simple Surface	1
13 Aug. 1960	2300	NW (land breeze)	10	Simple Surface	1
19 Aug. 1960	1100	SE (sea breeze)	10	Simple Surface	6
19 Aug. 1960	2230	NW (land breeze)	10	(Transitional)	1
20 Aug. 1960	1100	SE (sea breeze)	10	(Not known)	1
20 Aug. 1960	1630	SE (sea breeze)	10	(Not known)	2
27 Aug. 1960	1100	SE (sea breeze)	10	Simple Surface	2
4 Feb. 1961	1120	W	5	Simple Surface	1
5 Feb. 1961	2120	W	10	Simple Surface	1

The westerly wind in February 1961 may be considered as a wind from the sea on to the promontory and would contain the ducts which are probable over the sea. Average sea temperatures suggest that the structure shown in Figure 6 is reasonable near the Malaga area.

Occurrences during winter.—During the winter months November to March, 30 sets of observations were made. It was found that super-refraction occurred on 23 occasions during this period.

Ducts with no temperature inversion.—On a number of occasions it was noticed that a radio duct had formed in a layer of air in which there was no temperature inversion. At such times, however, there was a most noticeable drop in dew-point with height.

These examples occurred only in winter at times when a large number of echoes due to super-refraction were recorded, especially those thought to be Multiple Time-base (MTB) echoes. Table IV gives details of these events and

TABLE IV—ECHOES WITH NO TEMPERATURE INVERSION THROUGH THE DUCT

Date	Type of duct	Rate of fall of dew-point through duct	Type of echoes received
15 Nov. 1960	Simple Surface and Elevated S	very rapid	ships
16 Nov. 1960	shallow Simple Surface	steady	none
19 Nov. 1960	(Transitional)	fairly rapid	ships
5 Feb. 1961	Simple Surface	rapid*	many ships and MTB
9 Feb. 1961	Simple Surface	rapid	many ships and MTB
11 Feb. 1961	Simple Surface	rapid	none
12 Feb. 1961 (0030 GMT)	Simple Surface	rapid	MTB
12 Feb. 1961 (1130 GMT)	Simple Surface	rapid	many ships and MTB
13 Feb. 1961	Simple Surface	rapid	none
14 Feb. 1961	Simple Surface	very rapid	none
24 Feb. 1961	Elevated S	steady†	none
28 Feb. 1961	Simple Surface	very rapid	MTB
28 Mar. 1961	Simple Surface	rapid	ships and MTB

*Isothermal through duct, †temperature inversion present (see Figure 4).
MTB is the abbreviation for Multiple Time-base.

shows that it is not absolutely necessary to have a temperature inversion in order that a duct may be formed. Since there is invariably a temperature inversion layer over the sea surface in this region during the summer months the author is unable to say that ducting would occur without such an inversion. In the winter, however, an inversion layer over the sea is not always present and results show that on a good many occasions ducting did take place without an inversion being present at the surface. It was when this type of ducting took place that some of the best echoes due to super-refraction were recorded, especially those thought to have come from land beyond the normal radio horizon. An *M-h* curve drawn when there was no inversion present at the surface is shown in Figure 4.

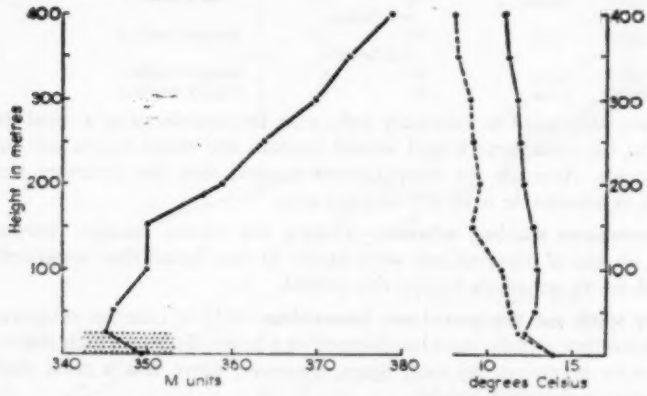

FIGURE 4—HEIGHT VARIATION OF THE MODIFIED REFRACTIVE INDEX, TEMPERATURE AND DEW-POINT FOR 2330 GMT ON 24 FEBRUARY 1961

——— Modified refractive index, – – – dew-point, ——— temperature.
Stippling shows the duct.

Further examples of ducts.—A selection of *M-h* curves is shown in Figures 5, 6, 7 and 8 together with an account of the type of echoes recorded on the days that these curves were plotted. Referring to Figure 7 it will be seen that the transmitter was lower than the duct; in such a case ducting cannot take place as the beam will enter the duct at an angle too great to allow it to be trapped. However the presence of the duct serves to bend the transmitter beam closer to the earth's surface than would normally be the case so that distant land echoes somewhat beyond normal range could well be recorded. In the case under consideration no ship echoes at all were seen but echoes from distant land were.

Conclusions.—These observations have shown that the super-refraction of radar waves can take place when a lapse of dew-point exists without an inversion of temperature within the air structure in which the duct is formed.

The propagation of side lobes is greatly enhanced when super-refractive conditions are in evidence. This could cause some misleading information to be recorded by ships' radars in coastal waters.

It would appear that Gibraltar is an ideal place to carry out investigations of this type. Super-refractive conditions seem to be the rule rather than the exception for this area and no matter what the season of the year, extension of radar ranges will be much in evidence.

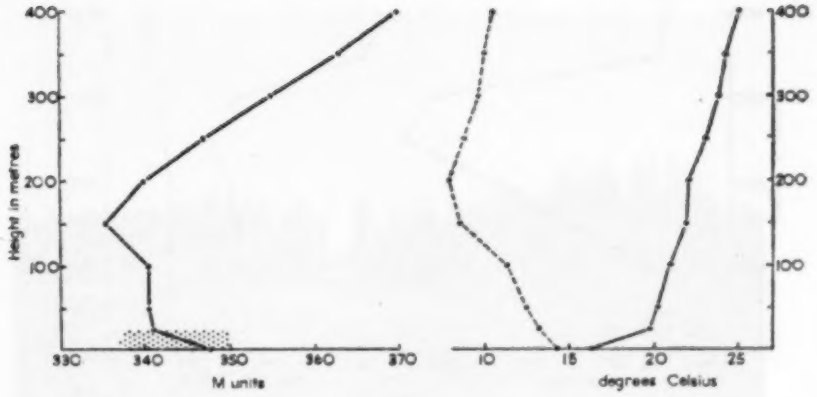

FIGURE 5—HEIGHT VARIATION OF THE MODIFIED REFRACTIVE INDEX, TEMPERATURE AND DEW-POINT FOR 2300 GMT ON 5 JULY 1960

——— Modified refractive index, - - - dew-point, ——— temperature.
Stippling shows the duct.

The following types of echoes were received on this day:

(i) Ship echoes up to a range of 95,830 m;

(ii) Multiple Time-base echoes from North African coast in the vicinity of Oran.

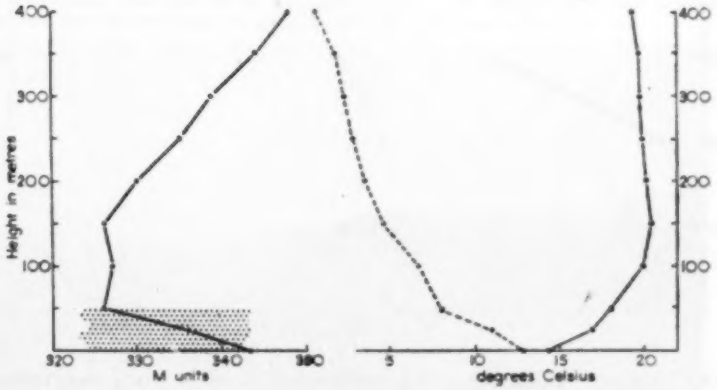

FIGURE 6—HEIGHT VARIATION OF THE MODIFIED REFRACTIVE INDEX, TEMPERATURE AND DEW-POINT FOR 1130 GMT ON 5 FEBRUARY 1961

——— Modified refractive index, - - - dew-point, ——— temperature.
Stippling shows the effective duct.

The following types of echoes were received on this day:

(i) Ship echoes up to 96,000 m;

(ii) Multiple Time-base echoes from North African coast in the region of Puerto Capaz.

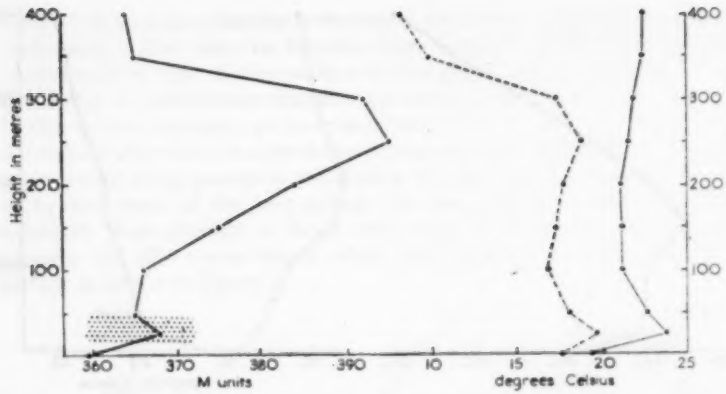

FIGURE 7—HEIGHT VARIATION OF THE MODIFIED REFRACTIVE INDEX, TEMPERATURE AND DEW-POINT FOR 1130 GMT ON 21 JULY 1961

——— Modified refractive index, – – – dew-point, ——— temperature.
Stippling shows the effective duct.
The following types of echoes were received on this day:
(i) Ship echoes—nil seen beyond normal radio horizon;
(ii) Multiple Time-base echoes from all along North African coast.

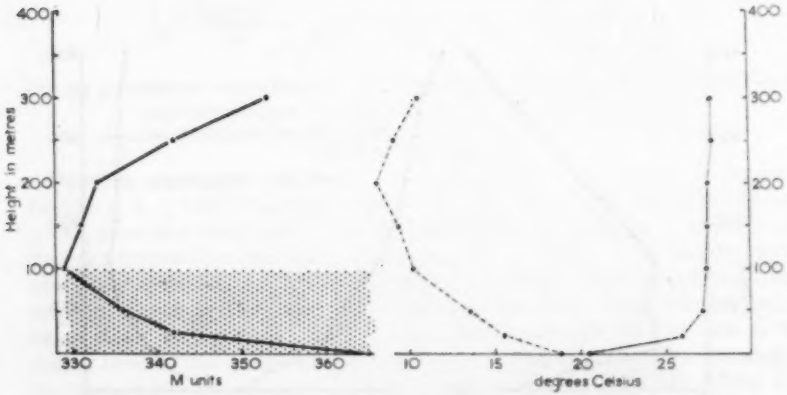

FIGURE 8—HEIGHT VARIATION OF THE MODIFIED REFRACTIVE INDEX, TEMPERATURE AND DEW-POINT FOR 1130 GMT ON 20 JULY 1961

——— Modified refractive index, – – – dew-point, ——— temperature.
Stippling shows the duct.
The following types of echoes were received on this day:
(i) Ship echoes up to 96,000 m;
(ii) Multiple Time-base echoes from all along North African coast.

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1. London, Meteorological Office. Handbook of meteorological instruments. Part II. London, HMSO, 1961, pp. 46–56.
2. London, Meteorological Office. Meteorology of radio propagation. London, HMSO, 1953.

Photograph by A. E. Dawson

PLATE I—THE NORTHERN PART OF THE OBSERVATORY GROUNDS AT ESKDALEMUIR

The chambers containing the magnetographs are under the mound in the centre; absolute magnetic observations are made in the huts near the trees. The seismological vault is about 300 yd beyond the trees and along the path shown in the background (see page 290).

Photograph by B. J. Gaist

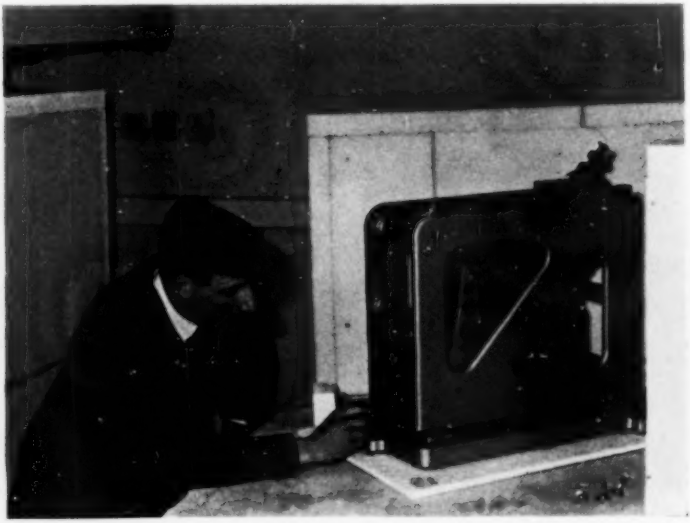
PLATE II—THE APPROACH TO THE NEW SEISMOLOGICAL VAULT AT MASS KNOWE NEAR ESKDALEMUIR OBSERVATORY

The entrance to the vault, in the hillside, is at the left beyond the gate (see page 290).

Photograph by B. J. Gorst

PLATE III—THE ENTRANCE TO THE NEW SEISMOLOGICAL VAULT AT MASS KNOWE

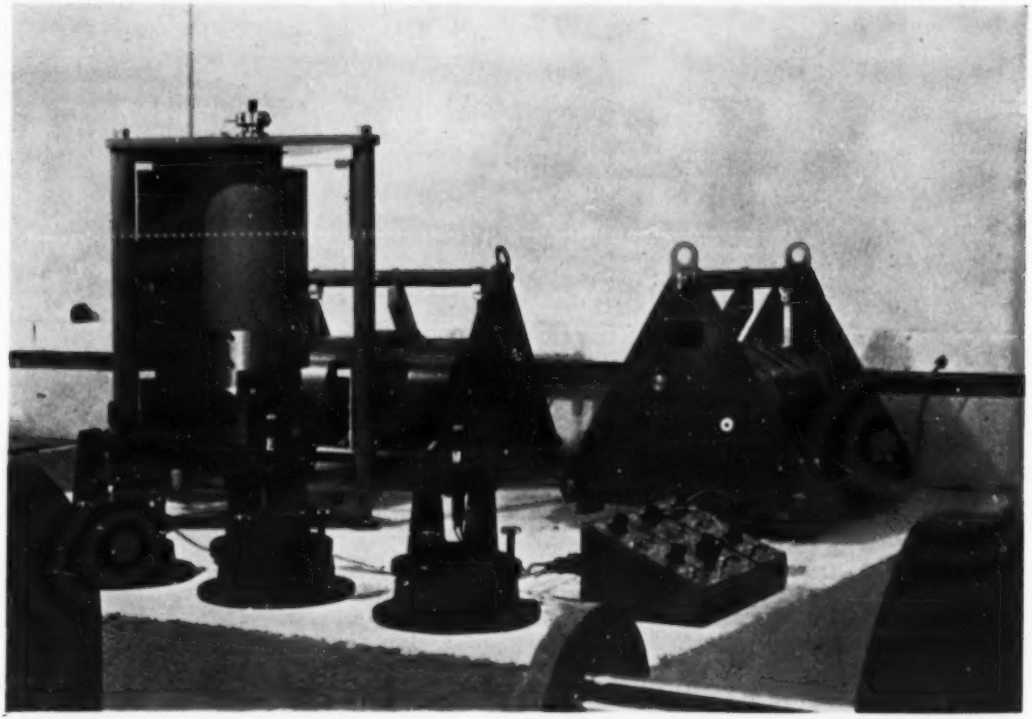
(See page 290.)



Photograph by B. J. Gorst

PLATE IV—THE ADJUSTMENT OF THE LEVEL OF THE LONG-PERIOD VERTICAL SEISMOMETER AT ESKDALEMUIR

The long-period seismometers are normally enclosed in a metal cover surrounded by an expanded polystrene cover to eliminate air currents (see p. 291).

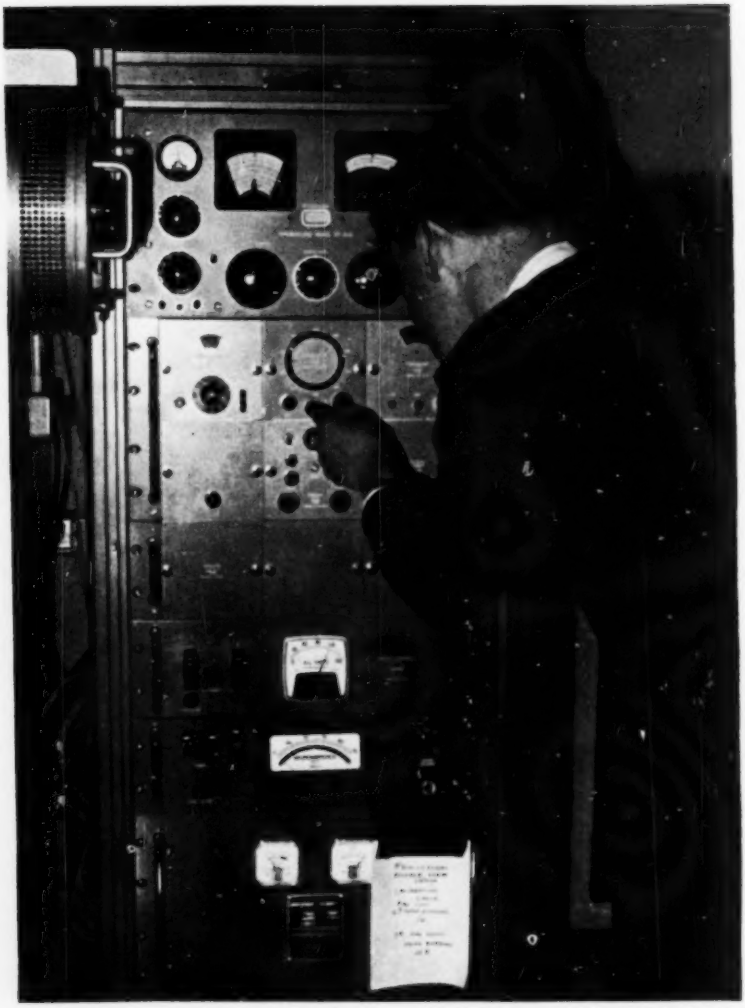


Photograph by A. E. Dawson

PLATE V—THE SHORT-PERIOD SEISMOMETERS WITH GALVANOMETERS AND CONTROL BOX AT ESKDALEMUIR

The vertical component instrument (the tallest one) is 36 inches high. (These instruments are normally enclosed in a metal container to eliminate air currents.) (See page 291.)

To face p. 305



Photograph by B. J. Gorst

PLATE VI—THE MAIN CONTROL PANEL FOR THE SEISMOLOGICAL INSTRUMENTS AT ESKDALEMUIR

The crystal clock error is being adjusted to zero as a daily routine after changing charts. The variable mains transformer used to control the heating of the vault can be seen to the top left (see page 291).

551.575.36(421)

THE YEAR-TO-YEAR VARIATION OF THE FREQUENCY OF FOG AT LONDON (HEATHROW) AIRPORT

By P. J. WIGGETT, B.Sc.

A study of the variation from year to year of the incidence of fog at London (Heathrow) Airport indicates that the frequency of occasions with visibility in the range 220–1100 yd has decreased significantly, whilst the frequency of thick fog (visibility less than 220 yd) is little changed during the period 1946–63.

In recent years members of the staff at Heathrow engaged on local forecasting have become aware of a decrease in frequency of fog at the Airport. This note reviews the evidence of the observational record to date to determine the magnitude of this decrease, and to see if any significant trend in the frequency is discernible. Previous notes[1,2] concerning fog at Heathrow have discussed at length the diurnal and annual variation of this element. Here, by contrast, the primary concern is to describe the year-by-year variation.

The record of visibility at Heathrow extends from early 1946 to the present. These data have been summarized on a monthly basis into the frequency of occasions with visibility in the ranges, less than 45 yd, 45–105 yd, 110–210 yd, 220–430 yd, 440–1090 yd for the eight main observational hours (0001, 0300, 0600.....2100 GMT). Inevitably, changes in recording and coding practices have occurred during this period, and consequently the classification of a few borderline cases in the early years prior to January 1949 is in doubt. However, the number involved is too small to have any significant influence on the final conclusions.

As Davis[1] has already shown, fog frequency at Heathrow is at a maximum in late autumn/early winter and falls to a minimum during the summer half of the year, April to September. The monthly summaries have been divided into 12-month periods July to June and the frequency totals for each of the 'years' from July 1946 to June 1963 derived. Thus, any variation in fog frequency due to persistence or other factors may be related to a specific fog season, and an arbitrary splitting of the winter maximum in the frequencies is avoided.

Table I gives the 12-months (July–June) totals for each of the visibility ranges considered.

TABLE I—12-MONTH (JULY TO JUNE) TOTAL OF 3-HOURLY OBSERVATIONS OF VISIBILITY WITHIN CERTAIN RANGES AT LONDON (HEATHROW) AIRPORT FOR THE YEARS 1946–63

Visibility	Year (12-month period commencing July)																
	1946	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62
yards	*number of 3-hourly observations*																
440–1090	133	114	100	90	82	85	114	93	62	64	84	65	94	42	47	64	71
220–430	23	27	33	37	19	19	45	25	12	17	15	18	38	15	15	18	19
110–210	20	16	25	37	14	15	32	25	15	10	23	17	35	15	18	13	10
45–105	34	26	53	21	12	27	36	39	21	26	30	21	47	23	14	18	28
< 45	10	13	19	17	7	13	31	8	3	16	7	5	28	18	3	6	22

These values have also been combined to give the frequency of occasions with visibility below specific limits in fog, the results being shown in Figure 1. On this basis the variation of frequency shows three marked maxima corresponding with the foggy winters of 1948–49, 1952–53, 1958–59. During these periods the frequencies in the upper ranges increase to approximately twice

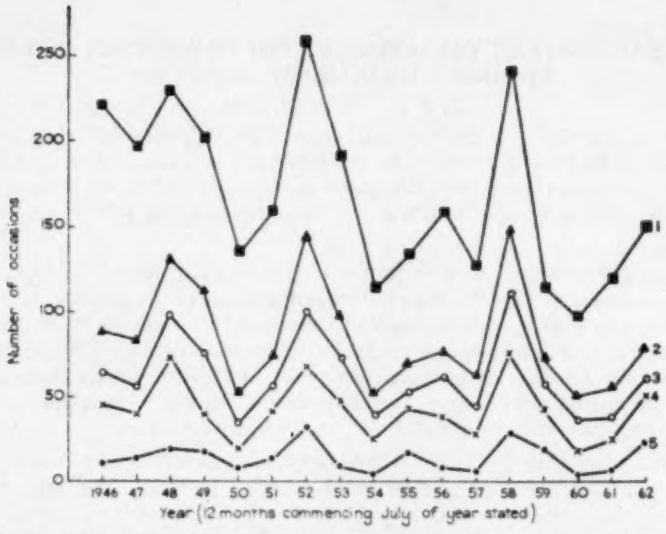


FIGURE 1—YEAR-TO-YEAR VARIATION OF FREQUENCY OF VISIBILITY AT LONDON (HEATHROW) AIRPORT

1—Visibility less than 1100 yards: 2—Visibility less than 440 yards: 3—Visibility less than 220 yards: 4—Visibility less than 110 yards: 5—Visibility less than 45 yards.

the value observed in the intervening years, whilst in the lowest range the amplitude is even greater being as much as 10 times the minimum values.

The variation of frequency for each range of visibility does not always conform to the pattern indicated in Figure 1, e.g. the first maxima for the ranges 110–210 and 220–430 yd both occurred in the winter of 1949–50, see Table I. Further, it is evident that the frequency of fog in the upper ranges has suffered an overall decline during the period thus confirming the impressions of the local forecasters at Heathrow. By contrast, the decrease in the lower ranges is much less pronounced, whilst the frequency of visibilities below 110 yd has remained virtually unchanged apart from the year-to-year variation.

The striking difference between the trend in the upper and lower ranges is emphasized in Figure 2 which shows 5-year running means for each range starting with the 5 years July 1946 to June 1951. For the range 440–1090 yd the mean frequency has dropped by nearly 40 per cent and a similar though less dramatic trend is evident in the middle ranges, the decline being about 10 per cent for visibilities between 45 and 105 yd. The values for the lowest range betray no significant trend. The best-fitting straight lines to each group of 5-year means have also been derived and are given in Table II.

TABLE II—EXPRESSIONS FOR BEST-FITTING STRAIGHT LINES TO 5-YEAR RUNNING MEANS OF VISIBILITY FREQUENCIES WITHIN CERTAIN RANGES

Visibility *yards*	Expression
440–1090	$f_1 = 100.9 - 3.37t$
220–430	$f_2 = 28.5 - 0.85t$
110–210	$f_3 = 22.9 - 0.34t$
45–105	$f_4 = 29.3 - 0.21t$
< 45	$f_5 = 14.1 - 0.15t$

Where f_1 to f_5 represent the 5-year mean frequency centred at t years after 1948.

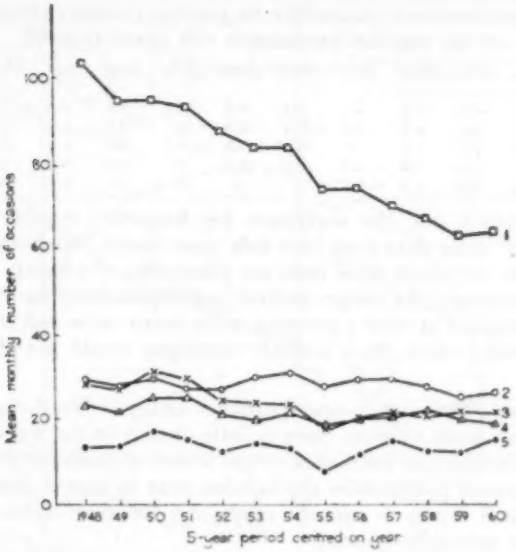


FIGURE 2—RUNNING 5-YEAR MEANS OF ANNUAL FOG FREQUENCY AT LONDON (HEATHROW) AIRPORT

1—Visibility 440–1090 yards: 2—Visibility 220–430 yards: 3—Visibility 110–210 yards: 4—Visibility 45–105 yards: 5—Visibility ≤45 yards.

For example, the 5-year mean frequency of visibility between 110 and 210 yd centred on 1958 can be expressed approximately as $22.9 - 3.4 = 19.5$ occasions, whilst the 5-year mean is decreasing at the rate of 3.4 occasions in 10 years. The expressions in Table II show that although the means in all ranges are declining, the rate differs greatly. The rate for the range 440–1090 yd is over 20 times as great as that in the lowest range. In terms of numbers of occasions, the mean decline in the lowest range is of little significance amounting as it does to less than 2 occasions in 10 years.

The distinction between smoke and water fog at Heathrow has been commented upon by Evans[2] who came to the conclusion that visibilities in the range 440–1090 yd were due largely to smoke pollution, though occasions arise when visibilities reported in this range relate to water fog that is in the process of formation or dispersal. Since the frequency of visibilities in the ranges below 440 yd shows the least decline, it is reasonable to assume that the frequency of water fogs has been similarly least affected. Thus the drop in frequency in the upper ranges must be directly related to a decrease in smoke pollution. This is in agreement with the steady decrease of smoke pollution in the London area since 1955 reported by Warren Spring Laboratory, Department of Scientific and Industrial Research.[3]

Finally, the monthly frequencies have been meaned by months and the results are given in Table III.

TABLE III—MEAN MONTHLY FREQUENCY OF 3-HOURLY OBSERVATIONS OF VISIBILITY WITHIN CERTAIN RANGES FOR THE YEARS 1946–63

Visibility *yards*	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
440–1090	12.5	10.9	10.7	2.1	1.2	0.3	0.4	0.6	2.5	12.3	13.8	15.2
220–430	3.8	2.5	2.3	0.4	< 0.1	0.2	< 0.1	0.6	1.3	3.6	3.8	4.6
110–210	3.6	2.5	1.2	0	0.4	0.2	< 0.1	0.5	1.4	3.3	2.3	4.5
45–105	4.3	1.4	1.8	0.2	0.2	0.1	0	0.2	0.9	5.6	5.9	7.4
< 45	1.9	0.8	1.0	< 0.1	0	0	0	0	0.1	1.7	3.2	4.6

Here it is evident that the maximum fog frequency occurs in December, whereas Davis[1] using data from only four years found that November was the foggiest month. Although these data are summaries of 3-hourly as opposed to hourly observations of the earlier analysis, a comparison of the two sets of data shows a difference of at most 5 per cent of the mean value and in general 3 per cent of the mean value. Such a small correction would not alter the above inference.

Conclusion.—The year-to-year frequency of fog at Heathrow has declined over the last 17 years whereas there is little change in the frequency of thick fog. The improvement in the higher ranges is seen as primarily the result of the reduction of smoke pollution in the London area in recent years, though the possibility that it is also in part the result of a variation of some synoptic or climatic factor cannot be ignored.

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2. EVANS, D. C.; A second report on fog at London Airport. *Met. Mag., London*, **86,** 1957, p. 333.
3. London, Department of Scientific and Industrial Research, Warren Spring Laboratory. Report for 1963. London, HMSO, 1964, p. 3.

551.577.21:551.577.37:519.2

THE RELATIONSHIP BETWEEN POINT AND AREAL RAINFALL IN PROLONGED HEAVY RAIN

By F. BURNS

Summary.—In two circular areas of 100 square miles each, it was found that on occasions of heavy rain the average difference between the rainfall reading at the centre of the area and an estimate of the areal rainfall was small.

Introduction.—It was required to investigate how far rainfall at a particular station was representative of that of the surrounding area, on occasions when falls of rain were heavy enough to result in a risk of flooding. The appropriate rates of rainfall were assumed to be of the order of 1 inch in 12 hours or less, or 1½ inches in 24 hours or less. The two areas studied were Glasgow and Edinburgh.

Glasgow area.—This contains a high density of long-established rainfall stations, and has relatively little variation in terrain as shown in Figure 1. The period used was 1939–61 and the number of stations within the circular area for any particular year varied from 15 to 23.

A continuous rainfall-record was available at Renfrew (or Abbotsinch) but other stations in the area reported only 24-hour rainfall amounts at 0900 GMT. Consequently, Renfrew's hourly records were examined; firstly, to identify occasions when considerable amounts of rain fell with few, if any, breaks; secondly, to select from them the occasions when practically all of the rain was

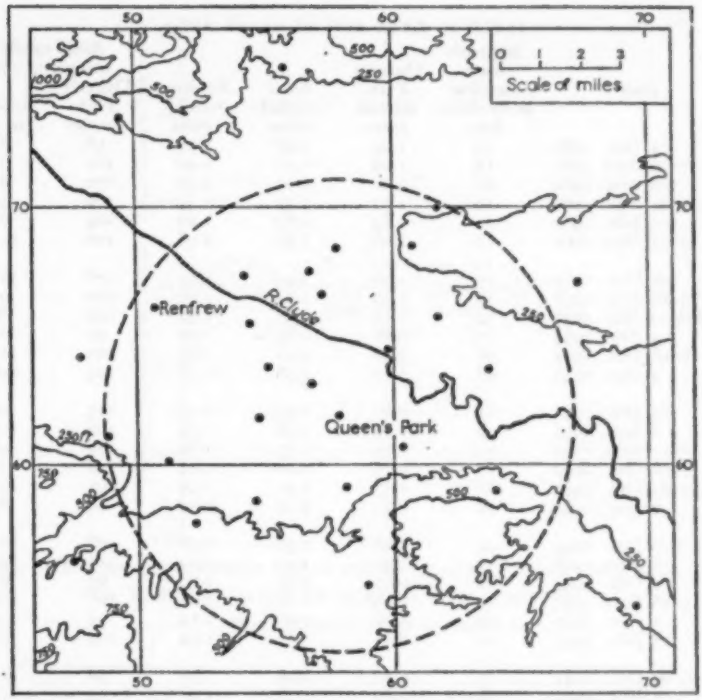


FIGURE 1—POSITIONS OF RAINFALL STATIONS AROUND GLASGOW

• Rainfall station. Contour heights are in feet.
National Grid lines are shown.

confined to discrete periods of 24, 48 or 72 hours. The *Daily Weather Report* of the Meteorological Office* was also consulted to ensure that the only cases used were those in which the rain was caused by features on a synoptic scale, e.g. by depressions, slow-moving fronts, etc. rather than by showers or thunderstorms. In all, 36 such instances were found; in these, no rain, or only very small amounts, fell outside the heavy rain period.

For each selected case, the total amounts of rain were plotted for every station in the area, and a circle, centred on Queen's Park, drawn to represent 100 square miles. Isohyets were then drawn at 0.1-inch intervals, and the areas between each successive isopleth within the circle measured by a planimeter. From these planimeter readings, the areal rainfall for each interval (the area between 0.1 inches and 0.2 inches, for example, was allocated a mean value of 0.15 inches), and finally that for the circular zone was calculated. This areal estimate for each occasion is tabulated in Table I, together with the approximate duration of the rainfall, the Queen's Park and Renfrew rainfalls, and the areal rainfalls as a percentage of the rainfalls at both Queen's Park and Renfrew. In Tables I and II, the 'days' quoted are strictly 24 hours beginning at 0900 GMT on the dates indicated.

*London, Meteorological Office. *Daily Weather Report.*

TABLE I—DATA FOR GLASGOW AREA

Date	Approximate duration at Renfrew *hours*	Queen's Park rainfall *inches*	Areal rainfall *inches*	Renfrew rainfall *inches*	Areal rainfall compared with Queen's Park *per cent*	Areal rainfall compared with Renfrew *per cent*
4 Dec. 1961	17	1.29	1.26	1.52	98	83
27–28 Sept. 1961	15	1.09	1.10	1.40	101	79
7–8 Aug. 1961	20	2.20	2.24	2.31	102	97
13–14 Sept. 1960	27	1.27	1.39	1.50	109	93
4–5 July 1960	12	0.84	0.87	1.20	104	73
12–13 May 1960	12	1.28	1.28	1.16	100	110
26 Oct. 1959	13	1.36	1.44	1.13	106	127
27–28 July 1958	17	1.59	1.74	1.80	109	97
28 Feb.–1 Mar. 1958	34	1.65	1.65	1.92	100	86
24 Nov. 1954	10	0.88	0.85	1.00	97	85
16–18 Oct. 1954	58	3.32	3.41	3.03	103	113
1–3 Dec. 1953	47	2.47	2.56	2.36	104	108
19 Dec. 1951	15	0.81	0.93	1.19	115	78
6 Sept. 1950	10	1.19	1.26	1.24	106	102
10–11 Sept. 1950	30	1.74	1.77	1.80	102	98
17–18 Oct. 1949	17	0.85	1.06	1.34	118	79
24–25 Oct. 1949	21	1.46	1.51	1.41	103	107
7 Aug. 1949	18	2.37	2.12	2.57	89	82
6–7 Jan. 1949	24	1.48	1.57	1.41	106	111
6 June 1948	12	1.25	1.41	1.14	113	124
12 Oct. 1947	12	0.97	0.92	1.10	95	84
15–16 Sept. 1947	12	1.09	1.10	1.02	101	108
5 Apr. 1947	12	1.16	1.06	1.14	91	93
13 July 1945	12	0.64	0.67	1.02	105	66
19–20 Oct. 1944	13	1.28	1.23	1.07	96	115
4 Nov. 1944	22	1.89	1.75	1.55	93	113
4–5 Feb. 1943	24	1.39	1.28	1.65	92	78
3 Oct. 1943	24	1.68	1.63	1.90	97	86
10 Dec. 1942	13	0.68	0.78	1.18	115	66
23 May 1941	15	1.10	1.27	1.32	115	96
15 Aug. 1941	17	1.35	1.37	1.15	101	119
19–20 Aug. 1940	4	1.08	0.93	1.02	86	91
8–9 Oct. 1940	36	1.44	1.56	1.92	108	81
14 Jan. 1939	12	0.92	0.86	1.01	94	85
6 Feb. 1939	12	0.80	0.82	0.98	103	84
7 July 1938	12	0.69	0.82	1.14	119	72

The differences (areal estimate minus rainfall at Queen's Park) are plotted against Queen's Park rainfall in Figure 2, and the graph indicates a fairly even scatter about the mean difference of 0.026 inches, with a slight tendency towards reduced scatter with increasing rainfall. The standard deviation is 0.10 inches.

To give an indication of how the difference (areal estimate minus station rainfall) would vary if the station were chosen near the edge of the circular zone, the mean difference (areal estimate minus rainfall at Renfrew) was calculated. Its value is –0.086 inches, with a standard deviation of 0.22 inches.

Edinburgh area.—A similar study was carried out for the Edinburgh area with Turnhouse and Firhill in place of Renfrew and Queen's Park. For the period 1948–63, examination of the continuous rainfall-record at Turnhouse revealed 34 occasions of 'heavy rain'—as defined earlier. The circular zone was centred on Firhill Tank, Colinton, and the number of stations in the zone varied from 15 to 28 (Figure 3).

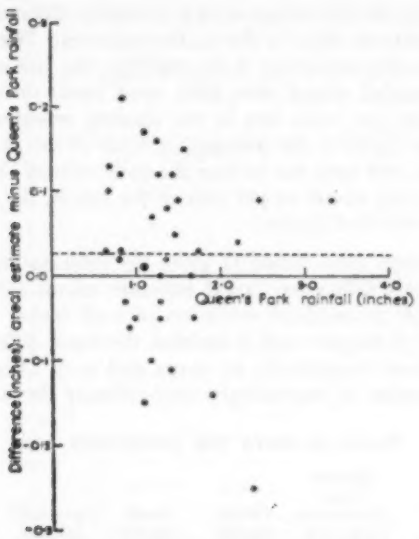


FIGURE 2—DIFFERENCE BETWEEN AREAL ESTIMATE AND QUEEN'S PARK RAINFALL FOR VARIOUS VALUES OF QUEEN'S PARK RAINFALL

– – – – – Mean difference, equal to 0.026 inches.

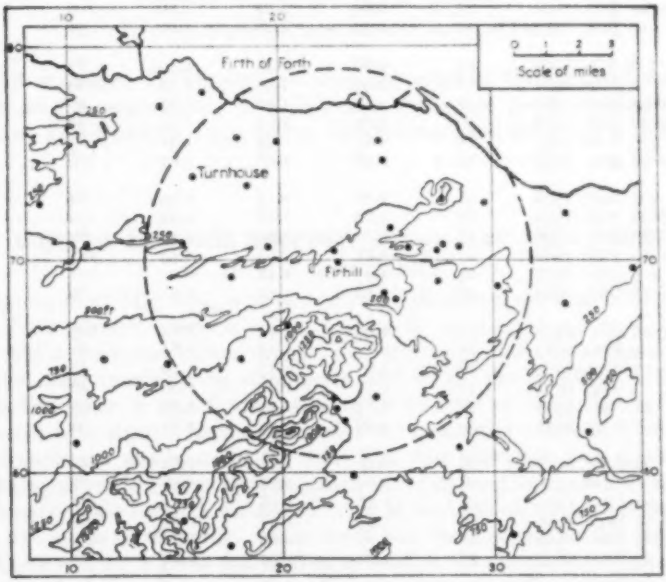


FIGURE 3—POSITIONS OF RAINFALL STATIONS AROUND EDINBURGH

• Rainfall station. Contour heights are in feet.
National Grid lines are shown.

Topographically, the Edinburgh area is markedly different from the Glasgow one, with a pronounced ridge in the south-south-west. Here, as there were no stations above 800 feet reporting daily readings, the isohyets over the higher ground (which reaches about 1800 feet) were based on values obtained by adding 25 per cent per 1000 feet to the reading reported from the nearest daily station. This figure is the average increase of the annual rainfall in the area per 1000 feet, and may not be true for daily rainfall; however as the area above 800 feet is only about 10 per cent of the whole, the value adopted will not greatly affect the final figures.

For the Edinburgh area Table II gives the information corresponding to Table I. The mean difference (areal estimate minus rainfall at Firhill) is −0.144 inches, with a standard deviation of 0.26 inches (Figure 4). If the extreme case, for 7–8 August 1948, is omitted, the mean difference and standard deviation are reduced respectively to −0.114 and 0.19. There is a tendency for the Firhill observation to increasingly over-estimate the areal rainfall as the

TABLE II—DATA FOR EDINBURGH AREA

Date	Approximate duration at Turnhouse *hours*	Firhill rainfall *inches*	Areal rainfall *inches*	Turnhouse rainfall *inches*	Areal rainfall compared with Firhill *per cent*	Areal rainfall compared with Turnhouse *per cent*
22–23 Nov. 1963	30	1.23	1.28	1.33	104	96
10 Nov. 1963	13	1.06	1.01	1.22	95	83
10–11 Sept. 1962	30	1.89	1.71	1.64	91	104
24 July 1962	14	1.20	1.14	0.92	95	124
20–21 July 1962	13	0.95	1.04	1.09	109	95
10 July 1962	12	1.37	1.26	1.22	92	103
7–8 Aug. 1961	34	2.88	2.45	2.30	85	107
12 July 1961	18	1.49	1.55	1.52	104	102
12–13 May 1960	14	1.12	1.02	1.23	91	83
27–28 July 1958	25	2.30	2.24	1.74	97	129
4–5 Nov. 1957	10	1.61	1.33	1.31	83	101
21–22 Jan. 1957	28	0.98	1.06	1.07	108	99
2–3 Sept. 1956	28	2.56	2.14	1.99	84	107
27–28 Aug. 1956	21	1.64	1.68	1.34	102	125
29 July 1956	13	1.70	1.47	1.43	87	103
11–12 June 1956	27	0.81	0.99	1.44	122	69
2–3 July 1955	24	1.47	1.48	0.91	101	163
16–17 Oct. 1954	30	1.58	1.40	1.31	89	107
14–15 Oct. 1954	19	1.63	1.71	1.69	105	101
3 Dec. 1953	21	2.11	1.73	1.61	82	107
16–17 Sept. 1953	16	1.67	0.97	1.19	58	81
7 Aug. 1952	22	1.35	1.11	1.00	82	111
21 Apr. 1952	18	1.15	1.14	1.13	99	101
6–7 Aug. 1951	29	2.86	2.75	2.83	96	97
22 July 1951	19	1.10	1.27	1.53	115	83
30 Apr.–1 May 1951	18	1.80	1.59	1.56	88	102
21 Nov. 1950	23	1.45	1.18	1.14	81	103
10–11 Sept. 1950	29	1.44	1.38	1.76	96	78
24–25 Oct. 1949	21	2.27	2.09	2.31	92	91
23 Oct. 1949	10	1.62	1.37	1.18	85	116
6–7 Jan. 1949	19	1.31	1.42	1.37	108	104
14–15 Sept. 1948	12	1.50	1.46	1.53	97	95
11–12 Aug. 1948	24	2.40	2.33	2.06	97	113
7–8 Aug. 1948	43	4.24	3.08	2.90	73	106

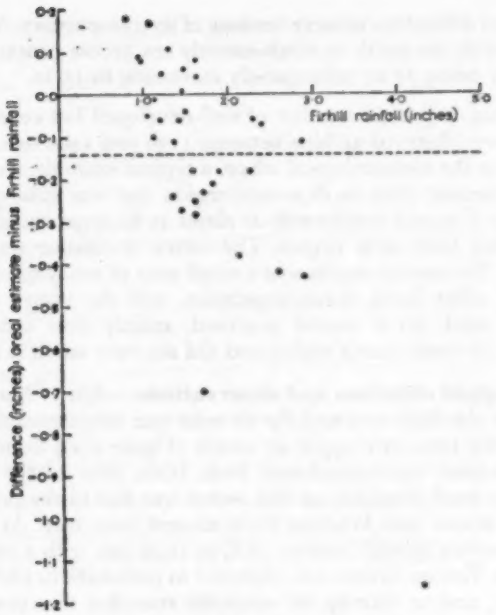


FIGURE 4—DIFFERENCE BETWEEN AREAL ESTIMATE AND FIRHILL RAINFALL FOR VARIOUS VALUES OF FIRHILL RAINFALL

– – – – – Mean difference equal to –0.144 inches.

total fall increases. If Turnhouse—near the edge of the circular zone—is adopted as the base station, then the mean difference (areal estimate minus rainfall at Turnhouse) is 0.030 inches, and the standard deviation 0.21 inches.

551.515.3

DUST WHIRLS AT IDRIS AIRPORT ON 31 MAY AND 1 JUNE 1964

By J. B. McGINNIGLE

At 1229 GMT on 31 May 1964, a large and very well-developed dust whirl tracked across Idris Airport, position 32°41′N 13°10′E, 14 n.miles south of Tripoli, North Africa. Its centre moved directly over the control tower and meteorological office area, causing some damage to and within the building. A window was broken when it was thrown against its frame and some items of radio equipment were thrown from a table adjacent to another window. A noise like a small explosion was heard at the time. The dust whirl was then observed to be tracking towards 120° at approximately 10 kt its base being about 50 yards in diameter while the top, estimated to be at about 2000 feet, appeared to be about 250 yards in diameter. As its track had been across mainly cultivated land, there was not a great deal of dust or sand in the vortex but its extent was clearly marked by a large number of pieces of paper and vegetation circling cyclonically at all heights. Sizable objects were easily kept aloft by the upcurrent. The circulation was observed for five minutes, by which time it was almost a

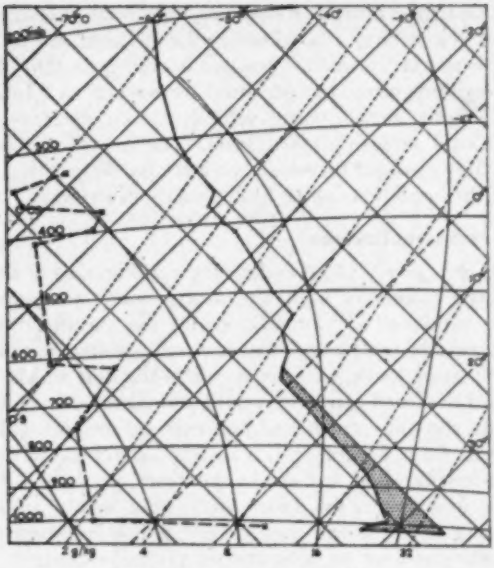
mile away and difficult to observe because of its transparency. With the passage of the dust whirl, the north to north-easterly sea breeze penetrated to Idris, its speed initially being 10 kt subsequently increasing to 15 kt.

The next day, 1 June, a number of well-developed but considerably smaller dust whirls were observed at Idris between 1130 and 1400 GMT. Although none tracked near to the meteorological office, a typical example of one of these dust whirls was observed close to its source region and was subsequently followed for 14 miles as it moved northwards at about 40 kt approximately parallel to a road connecting Idris with Tripoli. The vortex circulation was again cyclonic at all heights. The source region was a small area of sandy ground, surrounded by trees and other fairly dense vegetation, and the vortex contained large quantities of sand. As it moved overland, mainly over sandy ground, the vortex was at all times clearly visible and did not vary much in size or intensity.

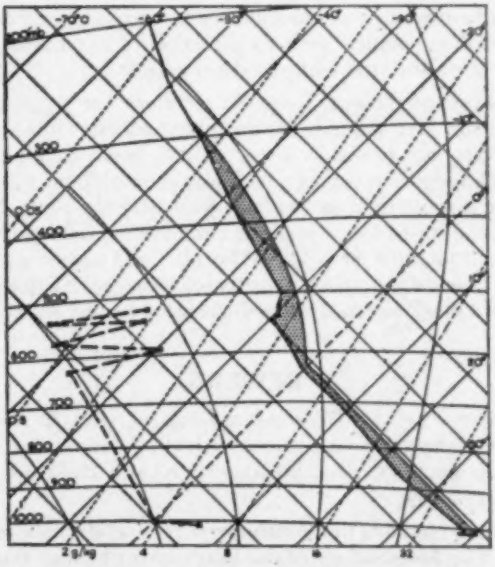
Meteorological situation and observations.—On 31 May 1964, pressure was slack over the Idris area and the air mass was very dry and unstable as can be seen from the 1200 GMT upper air ascent (Figure 1(*a*)) from Wheelus Field, situated 17 n.miles north-north-east from Idris, near to the Mediterranean coast. The low-level inversion on this ascent was due to the penetration of the northerly sea breeze into Wheelus Field around 1000 GMT. At Idris, however, the air temperature quickly rose to 36°C at 1200 GMT with a relative humidity of 13 per cent. The sea breeze was expected to penetrate to Idris between 1200 and 1400 GMT, and to take up its normally recorded direction and speed of north-easterly, 15 kt. As indicated in Figure 1(*a*), a convection path superimposed on this ascent using the Idris 1200 GMT air temperature and dew-point follows the dry adiabat to 630 mb, where the condensation level and the normal upper level of convection are coincident. A large positive energy area exists, as marked on Figure 1(*a*).

At the time of passage of the dust whirl, the meteorological office barograph showed an instantaneous fall and rise of 3.5 mb; the M.S.L. pressure reading at 1227 GMT was 1010.2 mb and the pressure indicated at the vortex passage was 1006.7 mb. At 1245 GMT, ground temperature readings were taken by placing a thermometer, shielded from the direct rays of the sun, with its bulb about ½ inch above the surface. The temperature of three representative types of ground was measured and the results were: rough grass 41.2°C, sand 43.2°C, asphalt chip road 45.0°C. An environmental lapse rate of between 5 and 9°C therefore existed in the first 4 feet of the air at this time, with a superadiabatic lapse rate extending to at least 2000 feet, and a dry-adiabatic lapse rate to 630 mb. The use of the ground temperatures as measured at 1245 GMT would produce an even larger positive energy area than that shown in Figure 1(*a*).

On 1 June, the development of a complex depression over Algeria and Tunisia caused a strong southerly gradient over the area and the surface wind at Idris increased overnight to become south-easterly 15–20 kt by 0700 GMT, with gusts to 25–30 kt by 0900 GMT. Because of this strong surface wind, there was no sea-breeze penetration at either Wheelus Field or Idris on this day, and the air temperature at both stations increased rapidly during the morning to 38°C at Wheelus and 40.6°C at Idris at 1200 GMT, with a relative humidity of 8 per cent. Again Figure 1(*b*) shows the extreme dryness and instability of the air (1200 GMT ascent 1 June) but, in this case, the convection path using the



(*a*) 1200 GMT on 31 May 1964



(*b*) 1200 GMT on 1 June 1964

FIGURE 1—UPPER AIR ASCENTS FROM WHEELUS FIELD

———— Dry-bulb temperature, – – – dew-point temperature.

Positive energy areas are shown by stippling. Convection paths are based on the Idris surface temperature and dew-point at 1200 GMT on each date.

1200 GMT Idris air temperature and dew-point although extending to far higher levels than the previous day, is far closer to the environment temperature path thus producing a markedly smaller positive energy area than on the previous day. Also, although no ground temperatures were taken on 1 June, it is assumed that the much higher surface wind velocity would decrease the lapse rate between the ground and the 4-foot level. The use of an assumed ground temperature as above would therefore not increase the positive energy area as much as would the conditions of 31 May already described.

Discussion and conclusions.—

(i) *Dust whirls of 1 June.*—On this day, the combination of the very marked instability and the extremely high air (and ground) temperatures over the whole land area produced ideal conditions for the maintenance of developed dust whirls. Because of the strong surface wind, ground temperatures would vary with the exposure, and the source region of the dust whirls, by virtue of its sandy surface and sheltered exposure, would undoubtedly have a higher ground temperature than the more cultivated and exposed ground which surrounded it. As can be seen from Figure 1(*b*), a superadiabatic lapse rate would exist only in the first few hundred feet of the 1200 GMT ascent of 1 June, using the recorded Idris temperatures for 1200 GMT. This would indicate that the height of the dust whirls would not exceed a few hundred feet and those observed were estimated not to be of greater vertical extent.

(ii) *Dust whirl of 31 May.*—The only dust whirl observed on this day was very large and passed directly over the meteorological office at Idris. It is very significant that its passage was immediately followed by the penetration of the sea breeze and this, coupled with its direction of movement, indicates that the dust whirl was associated with the sea-breeze front.

The combination of the very unstable air mass, large positive energy area and very high air and ground temperatures, further allied to the marked horizontal convergence of the sea-breeze front, would be highly conducive to the formation of a vigorous vortex which would develop on the front as a wave depression. The vortex would move along the sea-breeze front with the direction of the wind in the lower levels and the circulation would probably be maintained to a few thousand feet. The Wheelus Field ascent gives the wind at 2000 ft at this time as 290°, 8 kt. It is therefore suggested that this very large dust whirl was a small vigorous wave depresssion on the sea-breeze front.

REVIEWS

Einfluss der Karpaten auf die Witterungserscheinungen (*Die II. Konferenz für Karpatenmeteorologie Budapest*, 13–15 *November* 1961), edited by Dr. J. Kakas, 6¼ in × 9½ in, pp. 297, *illus.*, Akadémiai Kiadó, Budapest V, Alkotmány Utca 21, 1963. Price: $9.50.

This publication contains the lectures, reports and discussions of the Second Conference on The Meteorology of the Carpathians held at Budapest in 1961. The First Conference was held at Smolnice and it was proposed that a Third Conference should be held in 1963.

The papers are written in Russian or German and summaries are given in Hungarian and English. The summaries, for the most part, are detailed and

adequately represent the substance of the papers concerned. In general, the English summaries are written in a sound colloquial style and this, together with the fact that all figure and table captions have English translations, should enable the English reader who has no Russian or German to obtain a great deal of value from the papers.

The volume, although it contains papers of general meteorological interest, deals mainly with the effect on the weather of the Carpathian Mountains (and of the Danube basin as a whole since the two are closely linked geographically and meteorologically). It may be felt by the British reader that our own mountains are remote physically and in scale from the Carpathian Mountains but many of the problems of Alpine meteorology occur also in this country and the research devoted to the peculiarities of mountain weather and climate discussed in this volume may have fruitful application to mountain areas in Britain.

The first paper consists of a review of research work in hydrometeorology in the Ukrainian sector of the Carpathians, and is followed by a group of papers which discuss rainfall. The Bodolai family has produced many stimulating papers on the relationship between meso-scale rainfall distribution and synoptic situations and on this occasion Mme Bodolai presents a discussion on the effect of friction-induced vertical velocities on the spatial and temporal distribution of precipitation. D. Szepesi discusses the effect of mountain ranges in inducing 'additional' precipitation. He demonstrates that, in certain situations, although a föhn effect may result in 'negative' orographic precipitation 15 kilometres to the lee of a mountain ridge, 'positive' orographic precipitation may be discerned a further 15 kilometres downwind due to lee waves.

A further group of papers discusses snow measurements, avalanches (of which there are several photographs), duration and extent of snow cover, etc.

Another loosely-related group of papers deals with temperature conditions in the Carpathians, the mapping of temperature distribution (particular reference is made to the difficulty of mapping temperatures in mountains because of local pools of cold air in valley bottoms and temperature inversions), and advectional influences as reflected by the frequency distribution of temperature anomalies.

Several papers deal specifically with synoptic meteorology. Three of these are rather specialized in that they discuss irruptions of cold air into the Danube basin and one of them considers the synoptic conditions which allow cold air to flow into the Pannonian Plain (that part of the Danube basin in which Belgrade is centred) simultaneously from two or more directions.

In a paper on methods for the investigation of orographically induced weather in the Carpathians, a wave-like distribution in 24-hour precipitation patterns, similar to the pattern which Parrey[1] discovered to the lee of the Peak District in England, is discussed.

W. Böer in a paper on synoptic climatology suggested that progress in dynamical climatology had been disappointingly slow since Bergeron first introduced the concept. Reasons for this and suggestions as to how further progress might be made were put forward by the author and by many speakers in the ensuing discussion.

The complexity of rainfall distribution in mountainous areas is illustrated in one of the most unusual rainfall maps the reviewer has seen. The map of annual rainfall (p. 228) is based on a network of more than 30 rain-gauges in an

area of 40 square kilometres to the south of Lunz and shows a marked rainfall maximum in the main river valley with amounts decreasing to minimal values on a plateau to the west and on a ridge to the east. Such a distribution is quite contrary to that usually observed in Britain.

Several papers discuss radiation-balance and water-budget in Carpathian areas. In one of these papers, on the roles played by radiative and advectional influences in the climatic pattern of Hungary, the ratio of the amount of precipitation which forms run-off to the amount which is returned to the atmosphere as evaporation is derived for various catchment areas of central Europe and also for the neighbourhood of London. Unfortunately, the ratio of 1:1 (p. 242) for the London area given is incorrect. For the major catchment the Thames to Teddington (an area of about 10,000 square kilometres) the ratio is about 1:2 and for the drier Lee at Feildes Weir (about 1000 square kilometres) it is nearer 1:3.

In the final paper, W. Lászlóffy stresses the interdependence of the states of the Danube basin hydrologically and meteorologically and puts forward a number of proposals for international collaboration. Dr. Dési, in the preface, also stresses this need, as, indeed, do many of the authors in the body of the volume.

The present work is a most happy example of international co-operation. Naturally, authors from Hungary, the host country, provide the greatest number of papers, but at least one paper appears from each of the following countries associated with the Carpathians and the Danube: Russia, Yugoslavia, Czechoslovakia, Poland, East Germany, Austria and Romania.

The standard of production of the volume is far higher than for most published proceedings of conferences and symposia and reflects great credit on the editors and on the Publishing House of the Hungarian Academy of Sciences. The reproduction of figures and photographs is excellent, the print is clear (and of a reasonable size), and misprints, the curse of multilingual proceedings of symposia, appear remarkably few.

J. GRINDLEY

REFERENCE

1. PARREY, G. E.; Unexpected rainfall at Watnall, 18 May 1958. *Met. Mag., London*, **89**, 1960, p. 71.

The physics of lightning, by D. J. Malan. 8½ in × 5½ in, pp. xvi + 176, *illus.*, English Universities Press Ltd., 102 Newgate Street, London, E.C.1, 1963. Price: 25*s*.

The appearance of a textbook covering, even if briefly, almost every aspect of the physics of lightning and its associated phenomena, is of obvious importance. This work undoubtedly achieves at least two of the writer's three aims, in providing material both for the general reader and for the student intending to take up work on lightning research. For the third of the purposes stated in the author's preface, the provision of a useful reference book, achievement is more doubtful. The work suffers to some extent by being dated, a fault almost inevitable in a textbook dealing with a continuously advancing subject.

Where references to other publications are given, they are far from complete, being limited to 12 published documents in a field which has produced an extensive volume of material.

The practical aspects of damage arising from lightning are mentioned only briefly. While the very real hazard to aircraft, arising from the violent turbulence associated with clouds from which lightning discharge is possible, could be accepted as being outside the subject of the physics of lightning as such, any reference to the effect of lightning in aircraft should include the risks associated with damage to ancillary equipment, such as radio, and not be limited to wing-tip to wing-tip strikes. The reasons for the usual immunity from damage from such strikes is also worthy of mention.

In dealing with lightning flash counters, the basic problem of knowing the area over which the count is made, or, if the area is world wide, of ensuring that each flash is counted only once, is not explained. No reference is made to the important international local lightning flash counter accepted as a standard by the International Radio Consultative Committee (CCIR).

Both the specialist in lightning physics and the meteorologist will find particular interest in the location of thunderstorms by radio direction finding, and descriptions are given of the two systems in regular use. Unfortunately there is no critical discussion of the relative merits and shortcomings of the two methods, while the lack of up-to-date detail is exemplified by reference to the stations of the British Sferics Network—the list is incomplete and one station mentioned has been closed for the past 10 years.

This book, while filling an undoubted requirement, would benefit from revision on points of detail and amplification in several important aspects. Despite this it forms a welcome introduction to a subject of great interest and importance.

A. L. MAIDENS

OBITUARY

It is with deep regret that we heard of the death of Mr. H. A. Scotney on 30 June 1964. Mr. Scotney, Senior Experimental Officer, retired on 30 November 1958 after 33 years in the Office. Our sympathy is extended to his widow and son.

CORRIGENDA

Meteorological Magazine, October 1963, p. 302, Table I, for the Fordingbridge values substitute the following:

	NW	*N*	*E*	*S*	*ACW*	*W*	*CW*	*C*	*AC*	*U*
Fordingbridge	1.0	0.3	2.5	4.6	0.3	3.3	2.8	4.3	0.6	4.8

Meteorological Magazine, June 1964, p. 171, in the bold subheading, for "stratosphere" read "troposphere."

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NOTICES

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